Plasma Power Station (PPS) v0.6

Keep it simple.
Meier-Moir Model for Cost of Electricity guides decisions.

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PPS provides technology insertion opportunities for Sandia's Baseline Design.

Subsystem	Baseline	Plasma Power Station
Target Chamber	Thick Li or FLiBe Wetted Wall Gas Fill	Thick LiXY Wetted Wall Vacuum Fill
Fusion Capsule	MagLiF wt Laser & B_z ~15 GJ Yield	QSDD ~600 MJ Yield
Driver-Capsule Coupling	Stamped Steel Vacuum RTL Post Hole Convolute Long MITL 0.1 per second	Cast LiXY Cylinders Inverse Diode Short MITL 3 per second
Pulsed Power Driver	250 MJ H_2O Dielectric LTD H_2O Dielectric Transformer 20 MV vacuum stack 65 to 100 MA dI/dt ~ 0.8 MA/ns	85 MJ MITL LTD Long MITL 0.1 MV vacuum stack 45 MA dI/dt ~1.6 MA/ns

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Tackle hardest part first—coupling driver to target.

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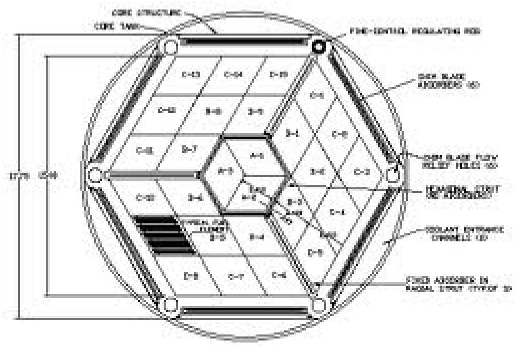
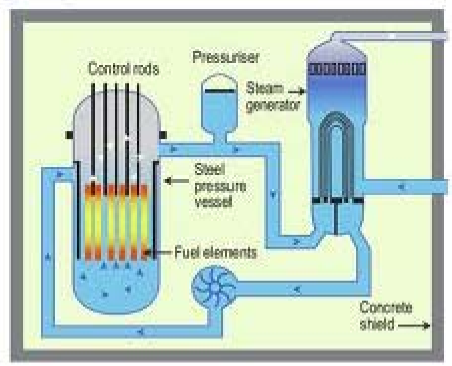


A typical Pressurised Water Reactor (PWR)



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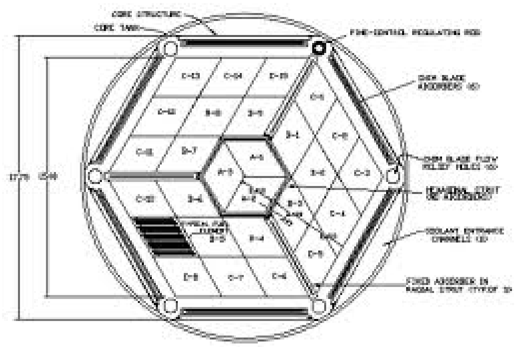

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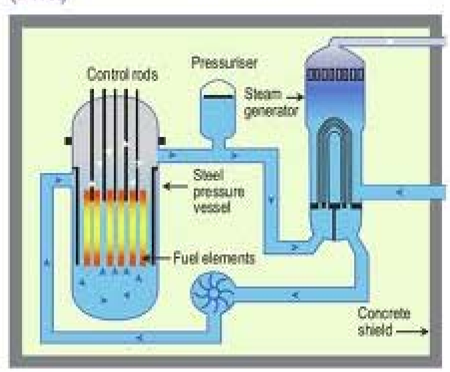

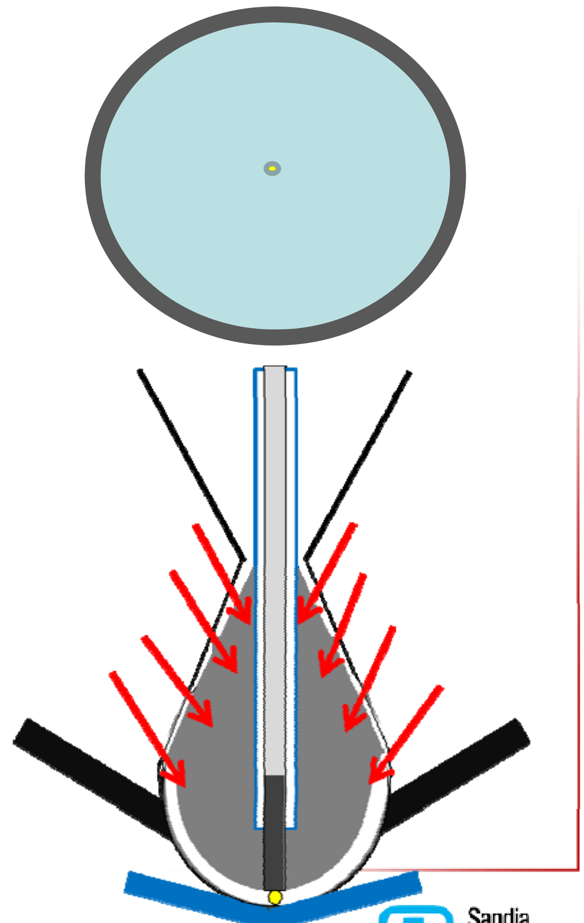

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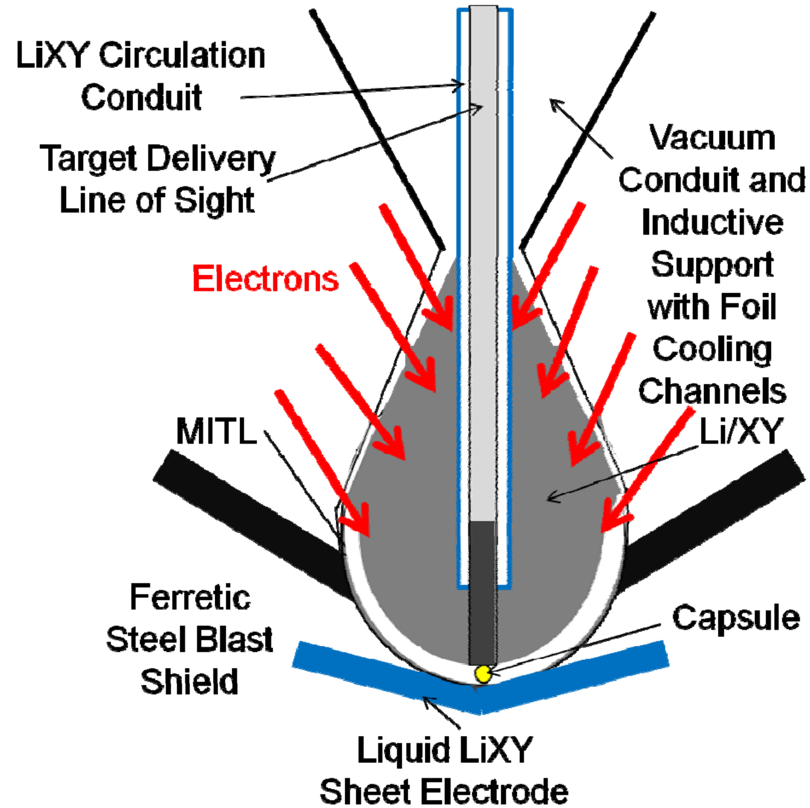
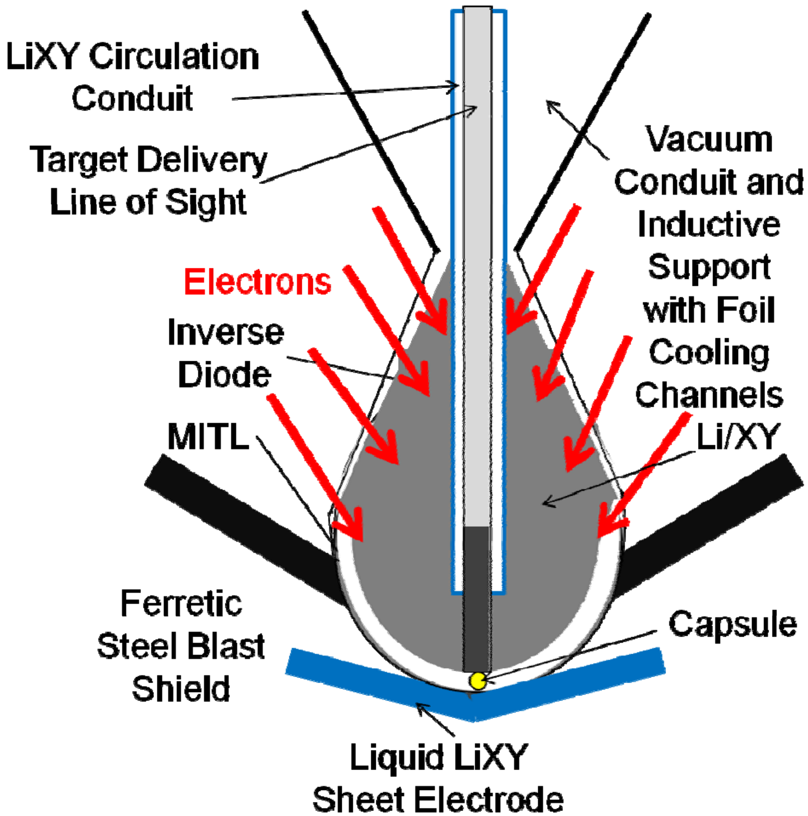
RTL design effectively enables moving the required mass.

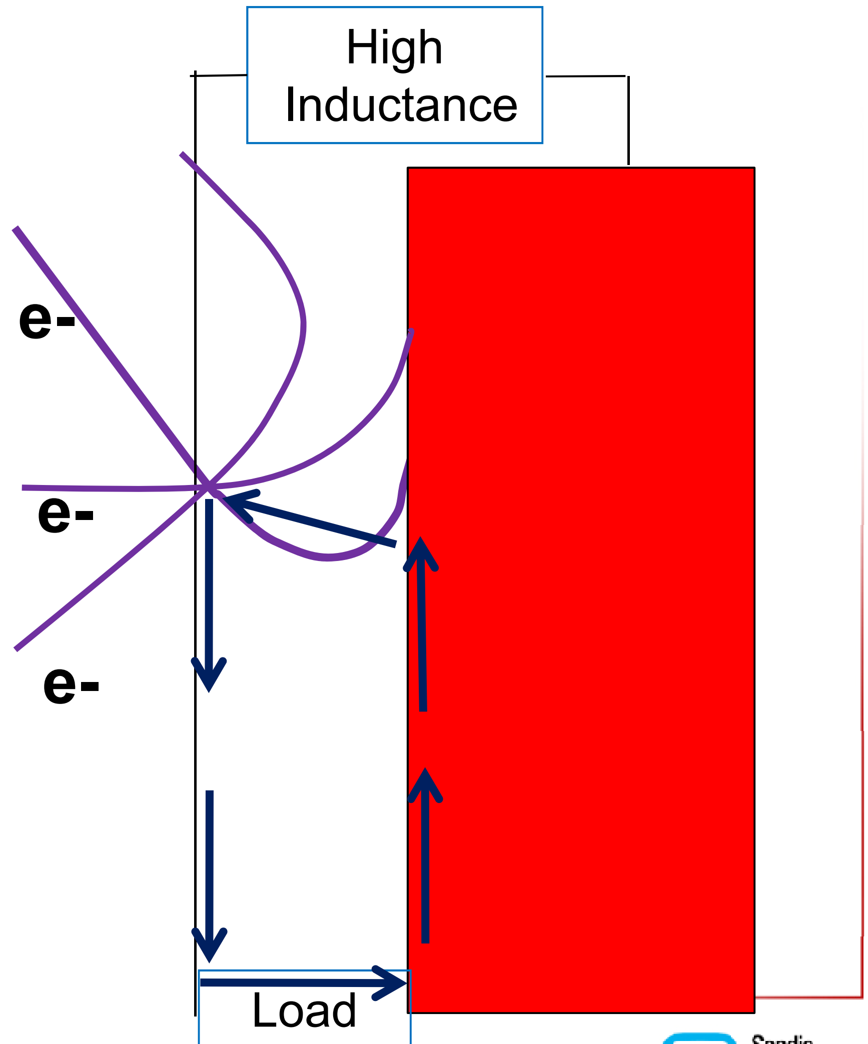
- $P_e \sim 10^9$ J/s
- $P_{th} \sim 2.5 \times 10^9$ J/s= C_p δT dM/dt
- $C_p \sim 10^3$ J/kg/^oC
- $\delta T \sim 500$ ^oC
- dM/dt~5000 kg/s

- Put it close to the capsule.
  - E. P. Velikov (1974)
  - Grant Logan (1993)
  - Dmitri Ryutov (2005, 2007)
  - VanDevender (2008)



Cylindrical RTL and Inverse Diode couple the driver to the capsule.

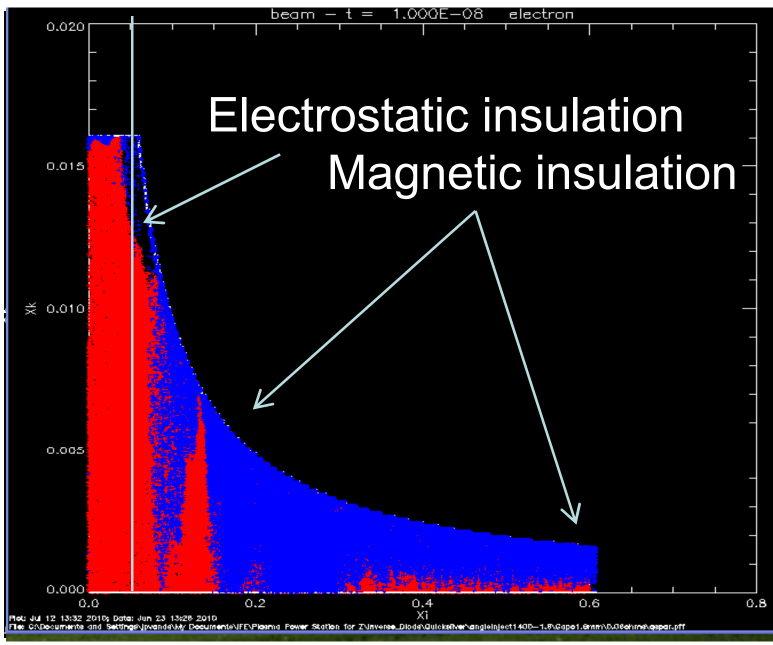


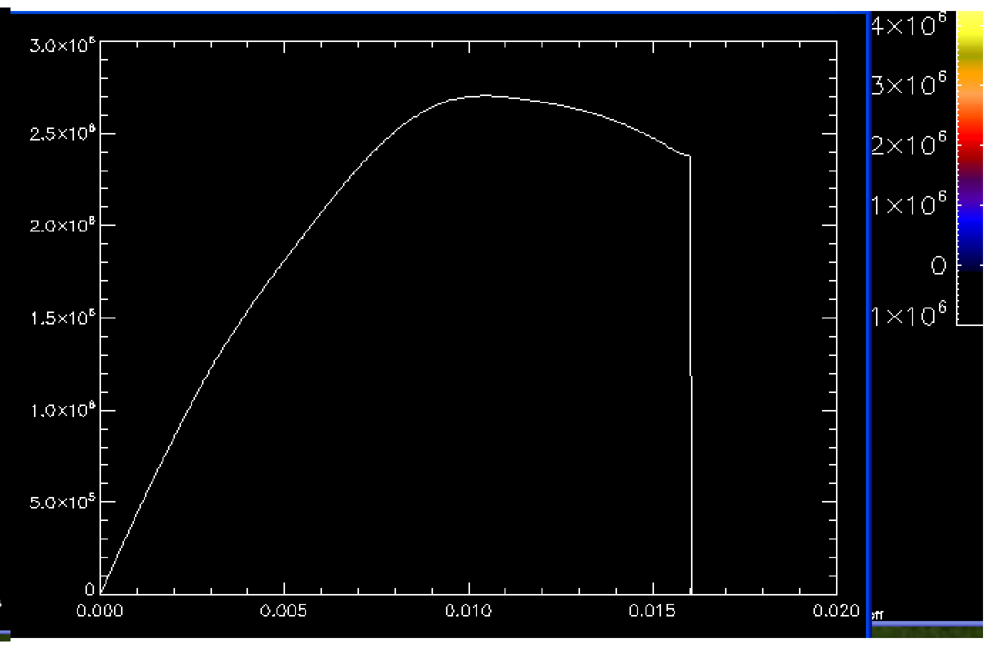


Space charge prevents secondary electrons from neutralizing injected current.

Red: Injected electrons
Blue: Electrons emitted
from cathode

Potential distribution across AK gap at r=0.05 m shows E-field reversal at cathode.





40 MA at 4 MeV injected and 33 MA at 2 MV at load without optimization

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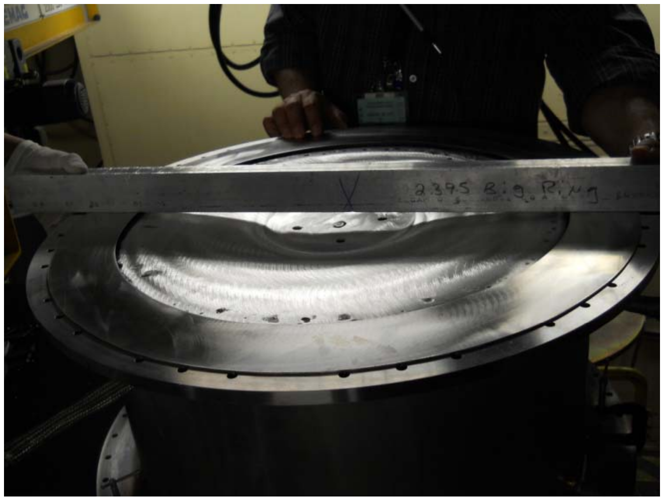
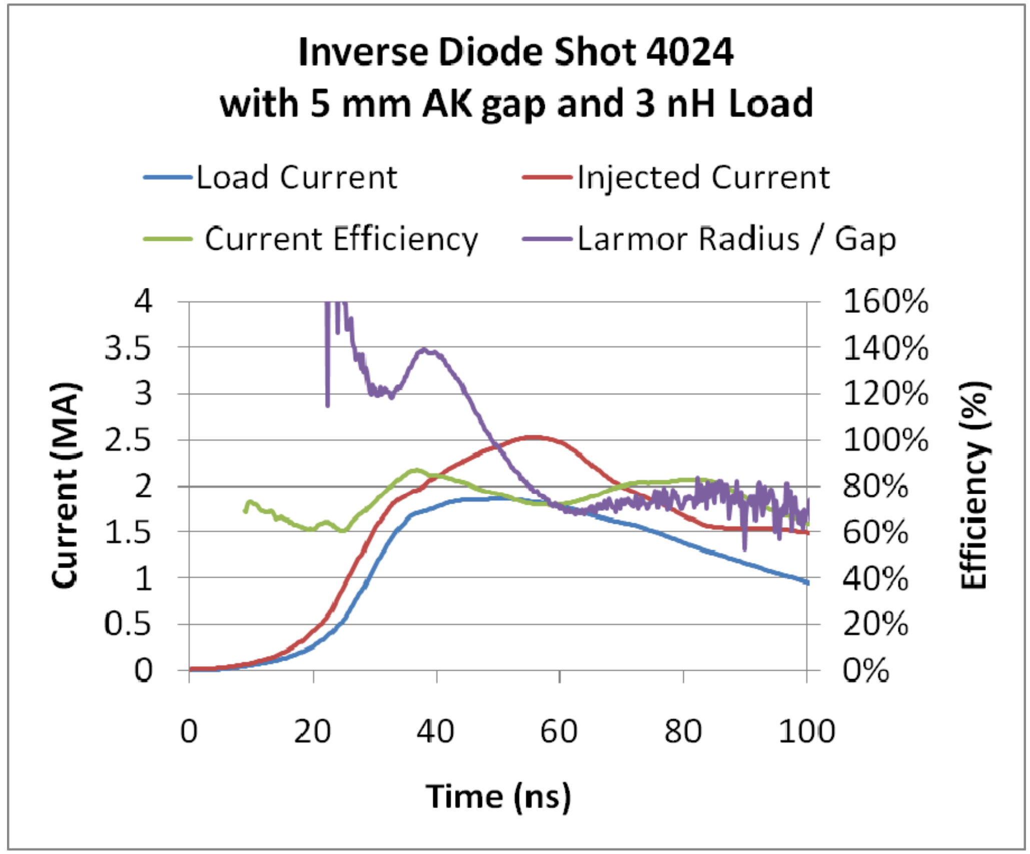
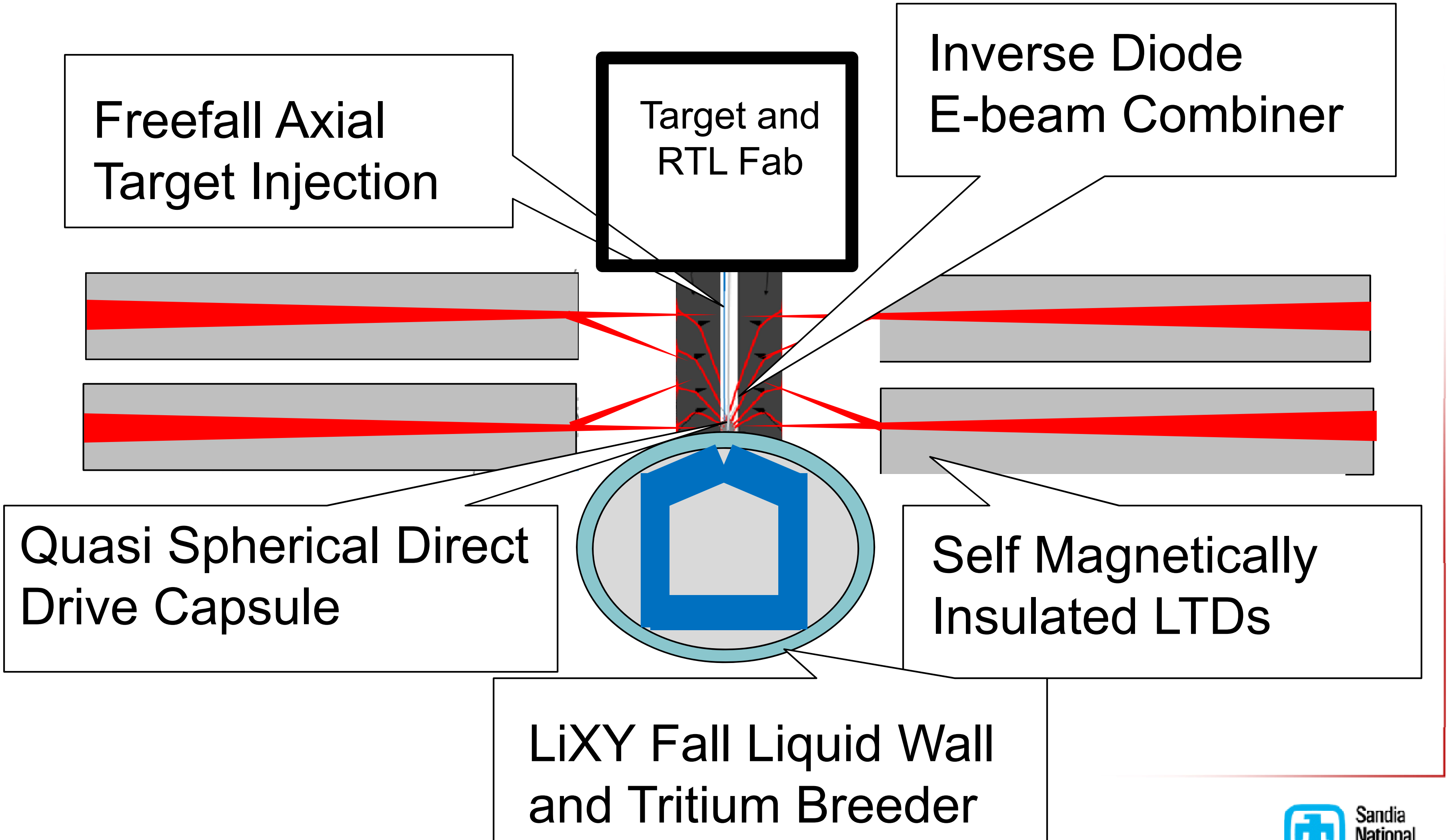
First Inverse Diode had ~70+/-10% collection efficiency.



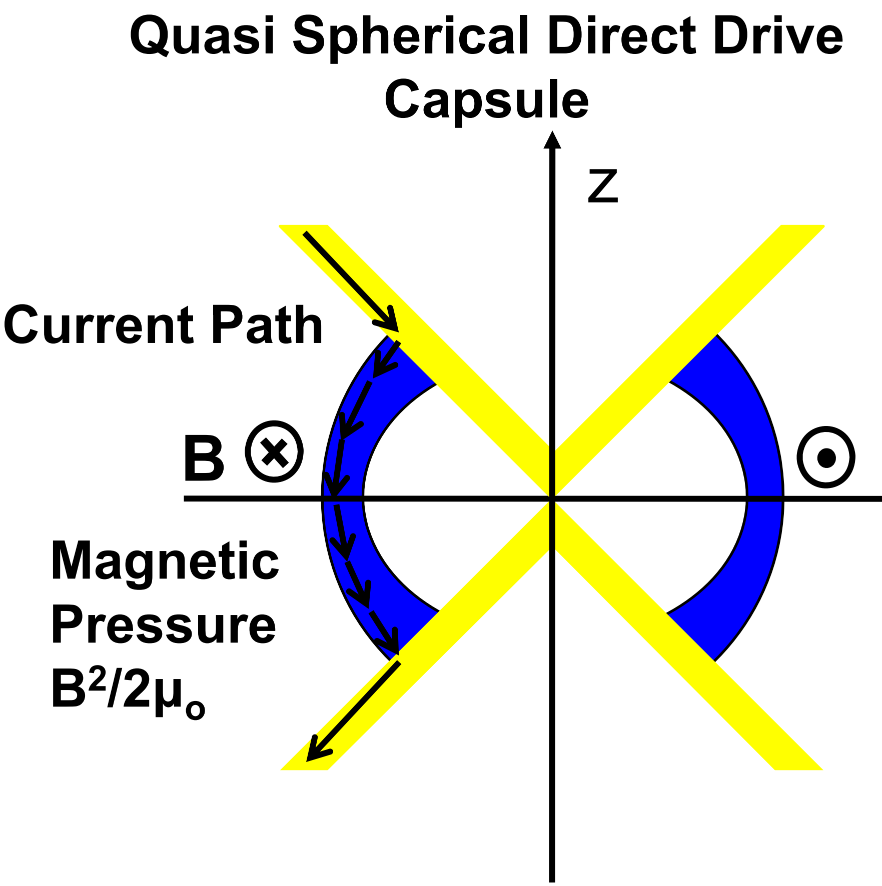


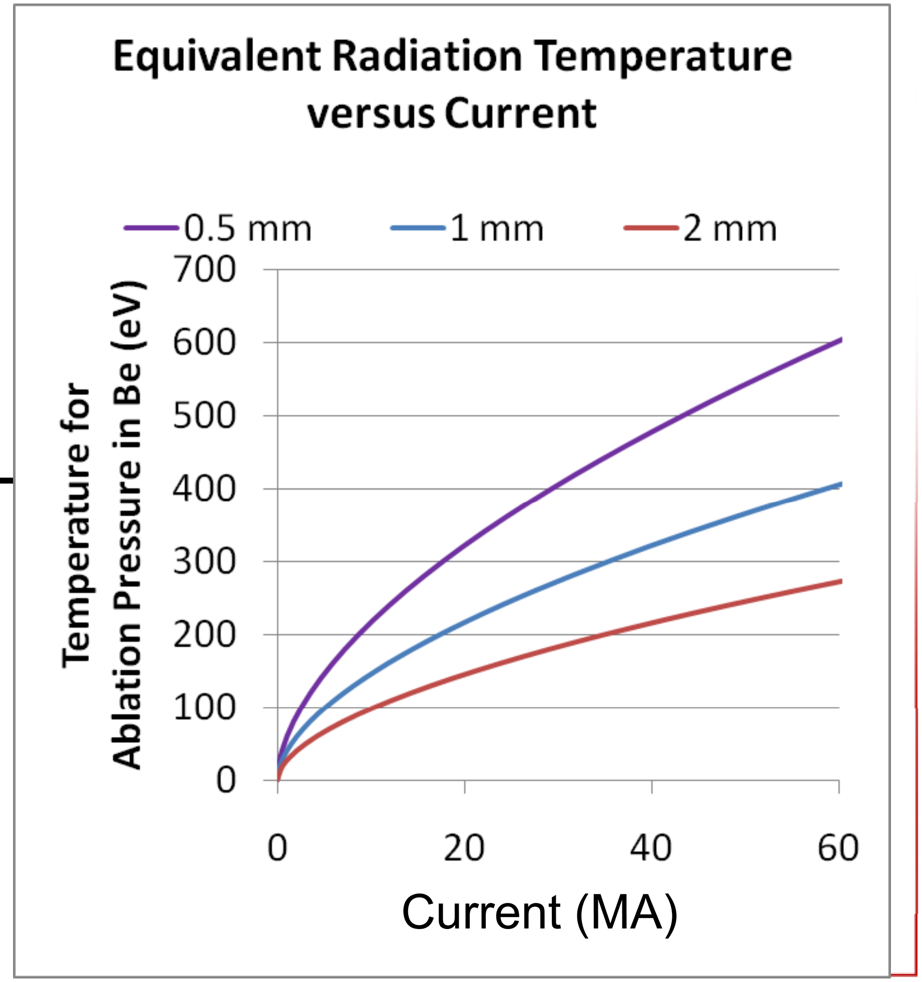
Saturn	PPS
2.2,2.8 MeV	7.5 MeV
2 kA/cm^2	0.5 kA/cm^2
2.5 MA	45 MA

Inverse Diode integrates QSDD Capsule and Magnetically Insulated LTDs in PPS.



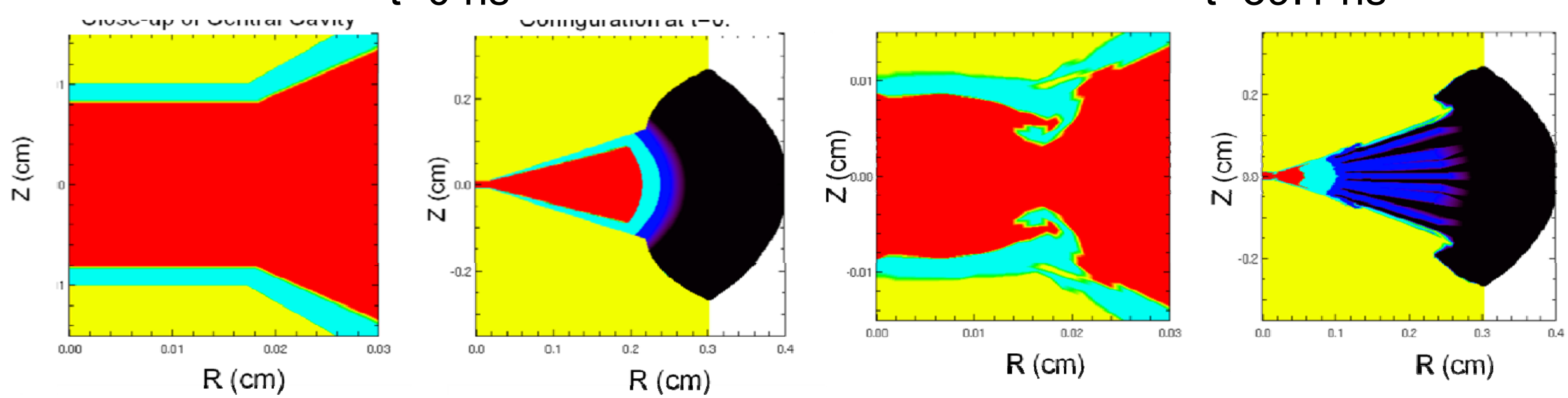
Magnetic pressure substitutes for ablation pressure in a hohlraum.



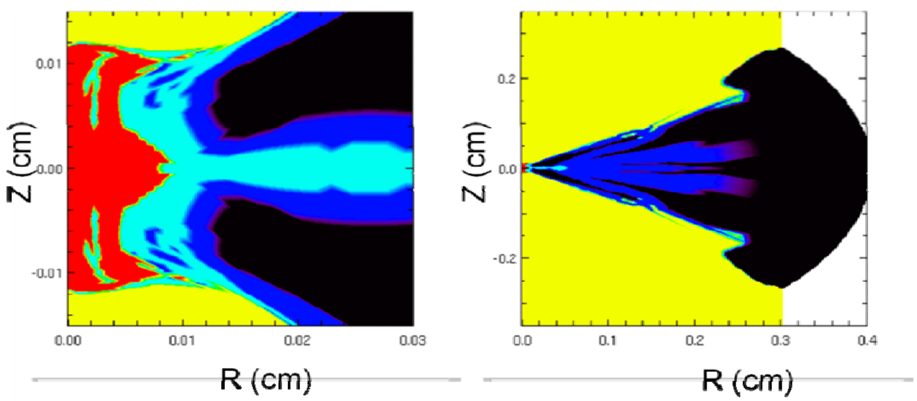


LASNEX Simulations show MRT Instability is benign for R_o/δ_o = 21 and 40 ns drive.

t=0 ns　　　　t=39.1 ns



t=41.6 ns



- 1 MJ yield in 1D and 2D
- 38 MA Z-Class Driver
- R_o/δ_o = 21

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Simulations reveal seven features that motivate QSDD.

1. Quantum Molecular Dynamics make **design less uncertain** than laser plasma interaction, wire initiation, and opacities make x-ray drive.
2. **>6 times more fuel energy** than x-ray drive.
3. Peak magnetic pressure **>10 times ablation pressure** of x-ray drive.
4. **Internal pulse shaping** automatically provides hot spot heating and adiabatic compression of main fuel.
5. Metal **conductor tamps expansion** during burn.
6. >4.5 MA current penetration into fuel gives alpha trapping and **reduce $\rho r_{ignition}$ by a factor of 5—without applied B or laser .**
7. **Possibility of MJ yields on a 40-ns, Z-class driver.**

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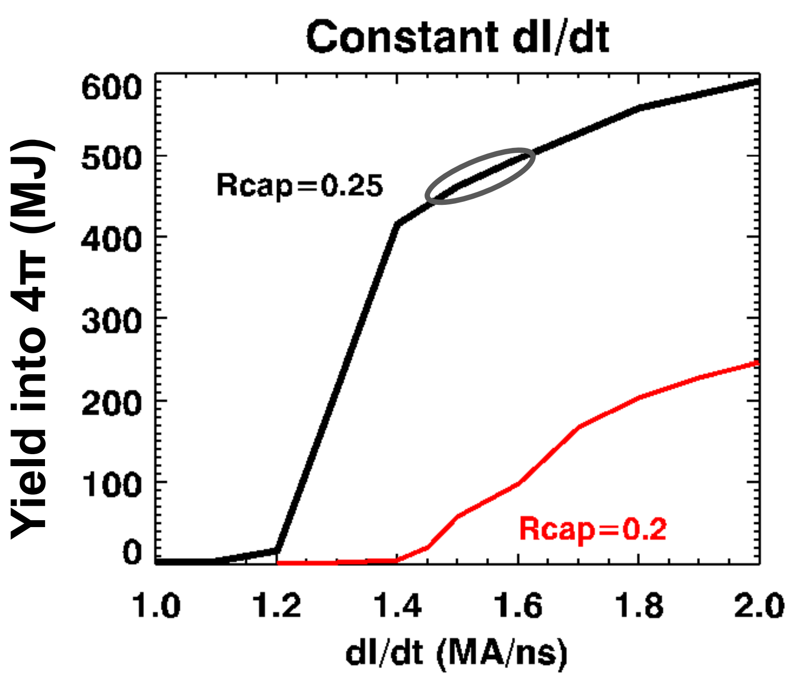
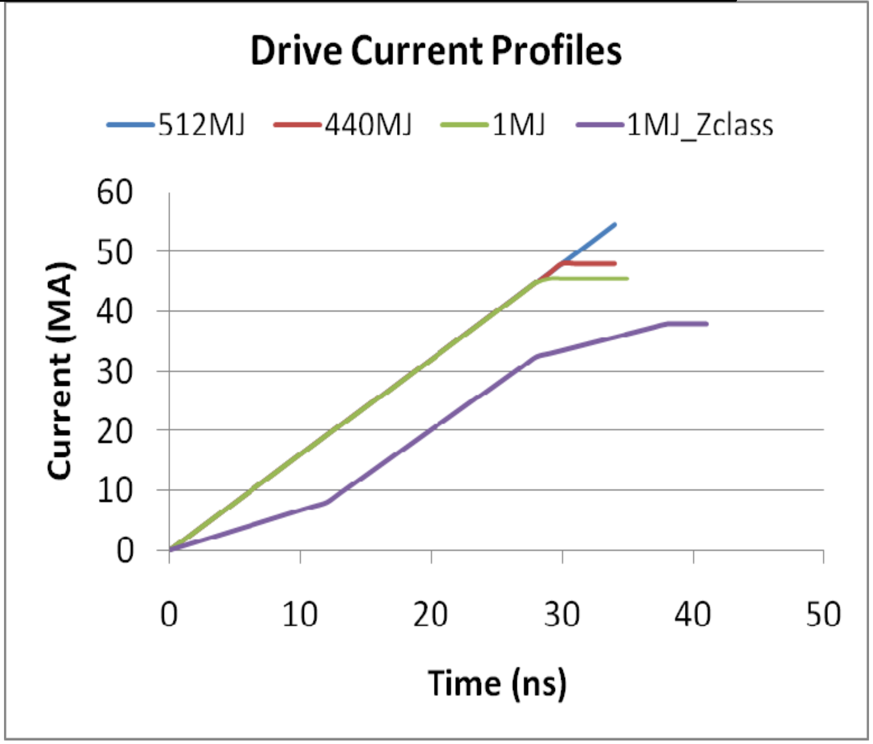
QSDD needs~ 38 MA for ignition and ~45 MA for high-gain on PPS.

Magnetic Rayleigh-Taylor instability allows initial aspect ratio of $R_o/\delta = 21$.





Producing dI/dt=1.5 MA/ns in a 2.5 mm radius capsule requires Inverse Diode.

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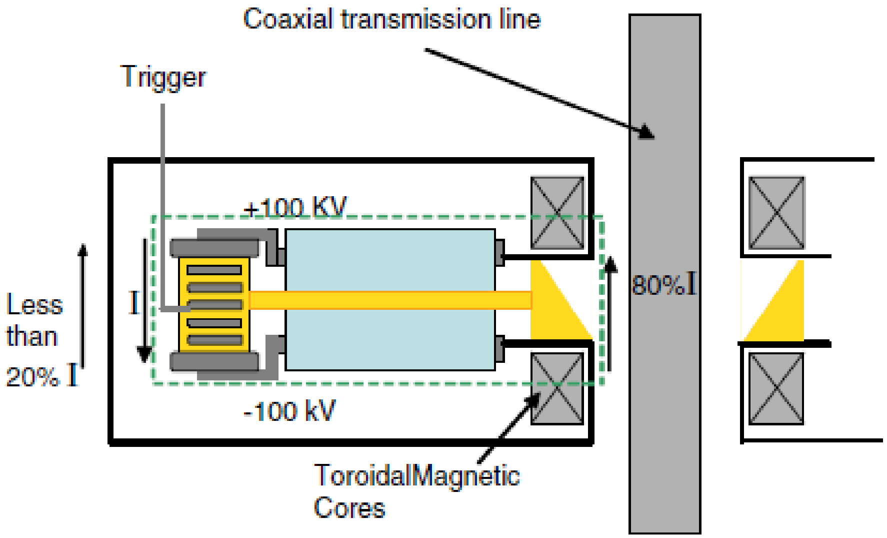
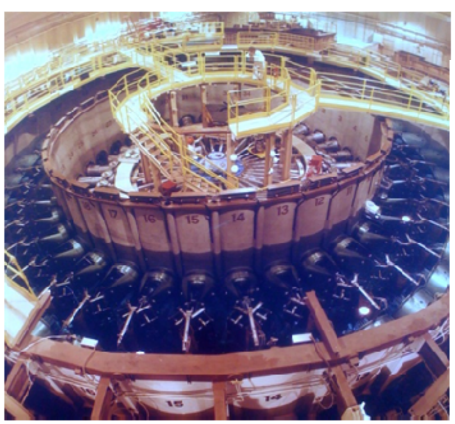
Magnetically Insulated, Linear Transformer Driver (MI-LTD) provides the modular e-beams.



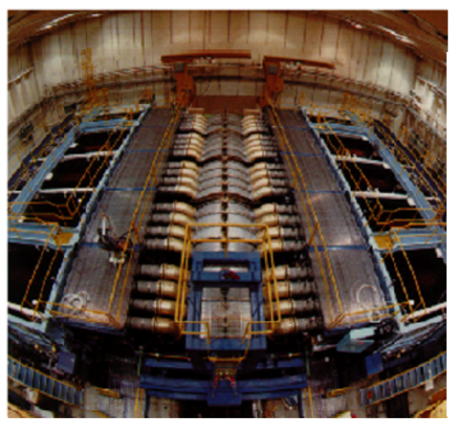
MYKONOS LTD Driver Test Bed

Prototype costs are:
$11/Joule
~10^{-4} cents/peak watt

PBFA-I, 2 MV, 12 MA



Hermes III, 18 MV, 0.7 MA



RHEPP II, 120 HZ

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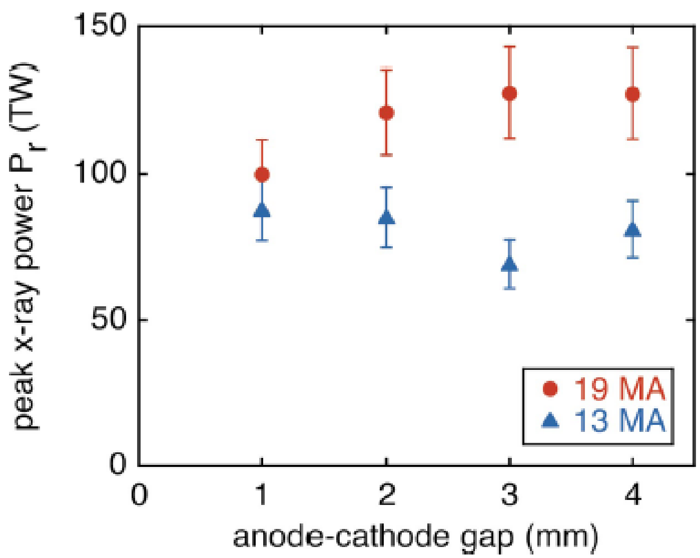
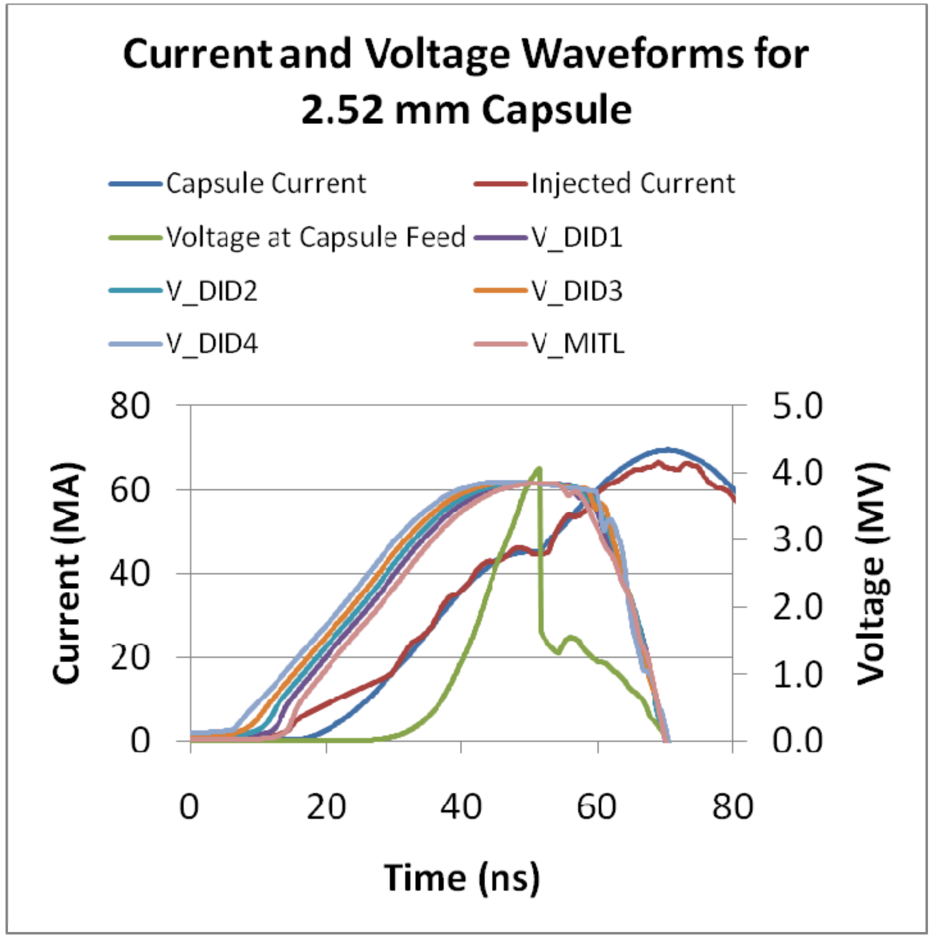
45 MA at 1.5 MA/ns in QSDD capsule drives the design of the rest of the PPS.

- Direct Inverse Diode
  - 1 meter radius
  - 560 A/cm^2
  - 7.5 MeV injected electrons
  - 1 mm minimum AK gap



Stygar, et al (2004)



LASNEX 1D simulation gives 630 MJ for 3.2 mm capsule.

PPS targets 3 Hz operation to produce power at Meir-Mohr Model COE of 7.6 cents/kW-hr.

First Units with 10% Cost of Capital and 1.85 MIT 2009 Study Factor to 2007$ gives 14.9 cents/kw-hr.

Input: Nc=number of chambers	1.00
Input: RR=rep rate in shots per chamber per second	3.00
Input: Discount or Hurdle Rate for attracting capital	**10.00%**
MIT Escalation Factor	**1.85**
Approximation to Pe (MW)	866
Eta=thermal to electrical	0.44
$/Joule for Bank Energy	2.00
Energy Store (MJ)	85.0
ηG_bank	7.5
Net Electrical Power (MW)	651
Output: COE in $/KWH	0.149
Y(E)=yield per chamber (MJ)	641
M=Energy multiplication factor	1.15
Net Electric Power (MW)	651

Proven Units with 7.8% Cost of Capital and 1.0 MIT 2009 Study Factor to 2007$ gives 7.6 cents/kw-hr.

Input: Nc=number of chambers	1.00
Input: RR=rep rate in shots per chamber per second	3.00
Input: Discount or Hurdle Rate for attracting capital	7.80%
MIT Escalation Factor	1
Approximation to Pe (MW)	866
Eta=thermal to electrical	0.44
$/Joule for Bank Energy	2.00
Energy Store (MJ)	85.0
ηG_bank	7.5
Net Electrical Power (MW)	651
Output: COE in $/KWH	0.076
Y(E)=yield per chamber (MJ)	641
M=Energy multiplication factor	1.15
Net Electric Power (MW)	651

QSDD Capsule, Cylindrical RTL, Survivable Inverse Diode, Magnetically Insulated LTD.

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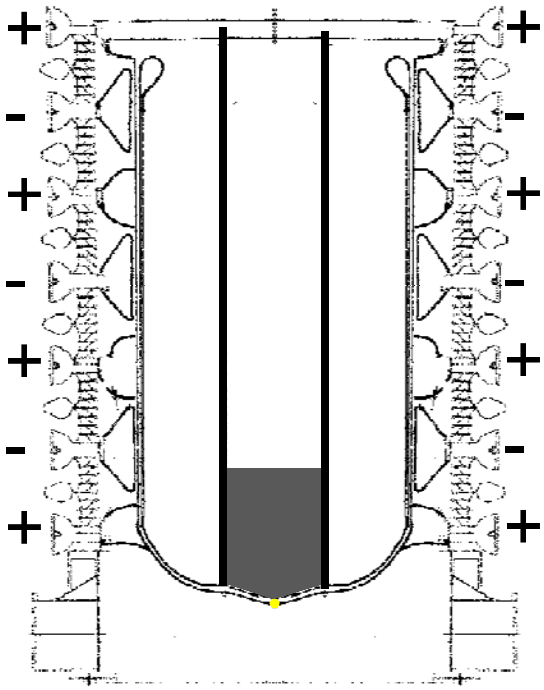
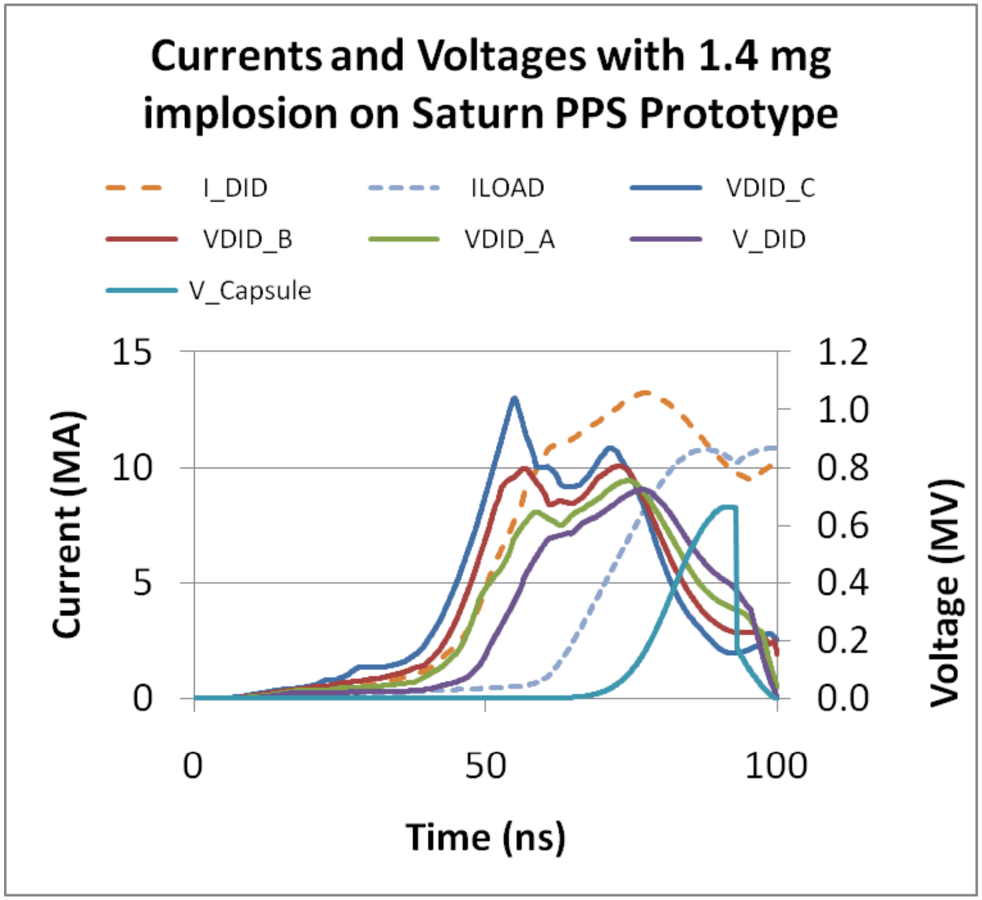
Saturn could prototype the PPS Inverse Diode, RTL, and QSDD Capsule.





QSDD baseline with 17.5 mg mass has 4 cm/ μs velocity.
QSDD surrogate with 1.4 mg mass has 22 cm/μs velocity.

PPS Version 0.6 has many issues and research opportunities.

- Better mitigation of wall instability
- Experimental demonstration of QSDD performance
- High-resolution Gorgon, LASNEX, or Hydra simulations at 500 MJ yield with dI/dt ~1.5 MA/ns
- Experimental demonstration of > 90% current efficiency with Direct Inverse Diode (DID)
- Survivable anode at 560 A/cm^2 electron injection
- 2D simulations of blast and radius for survivability
- Simulation of chamber recovery for 3 Hz operation
- LiXY working fluid with <3x10^{-5} Torr vapor pressure at 400 ^{o}C
- Liquid metal MITL anode
- Ignition on short pulse modification of Z

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Backup Slides

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Pulsed Power Driver	250 MJ H_2O Dielectric LTD H_2O Dielectric Transformer 20 MV vacuum stack 65 to 100 MA dI/dt ~ 0.8 MA/ns	85 MJ MITL LTD Long MITL 0.1 MV vacuum stack 45 MA dI/dt ~1.6 MA/ns

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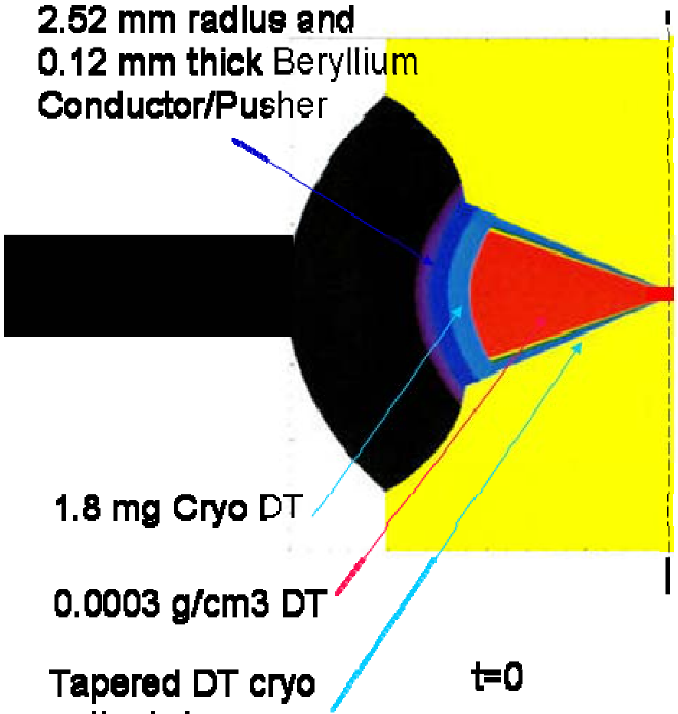
Quasi Spherical Direct Drive capsule offers 500 MJ yields with 85 MJ energy store.



Many issues are mitigated with a higher dI/dt.

- **Uniform Initiation**
- **Less growth of Magnetic Rayleigh Taylor instability**
- **Lower driver energy**
- **Higher ηG**
- **Lower Cost of Electricity**

2D yield is currently limited by a wall instability.
Three possible solutions are being examined with LASNEX.

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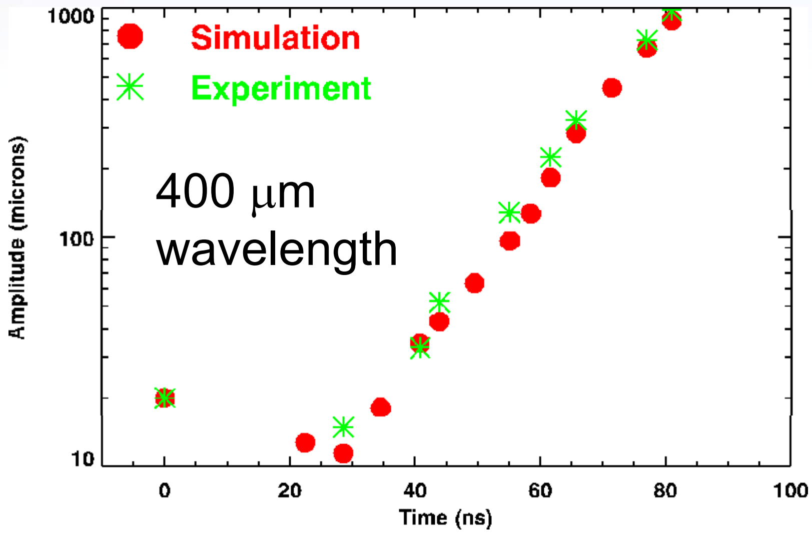
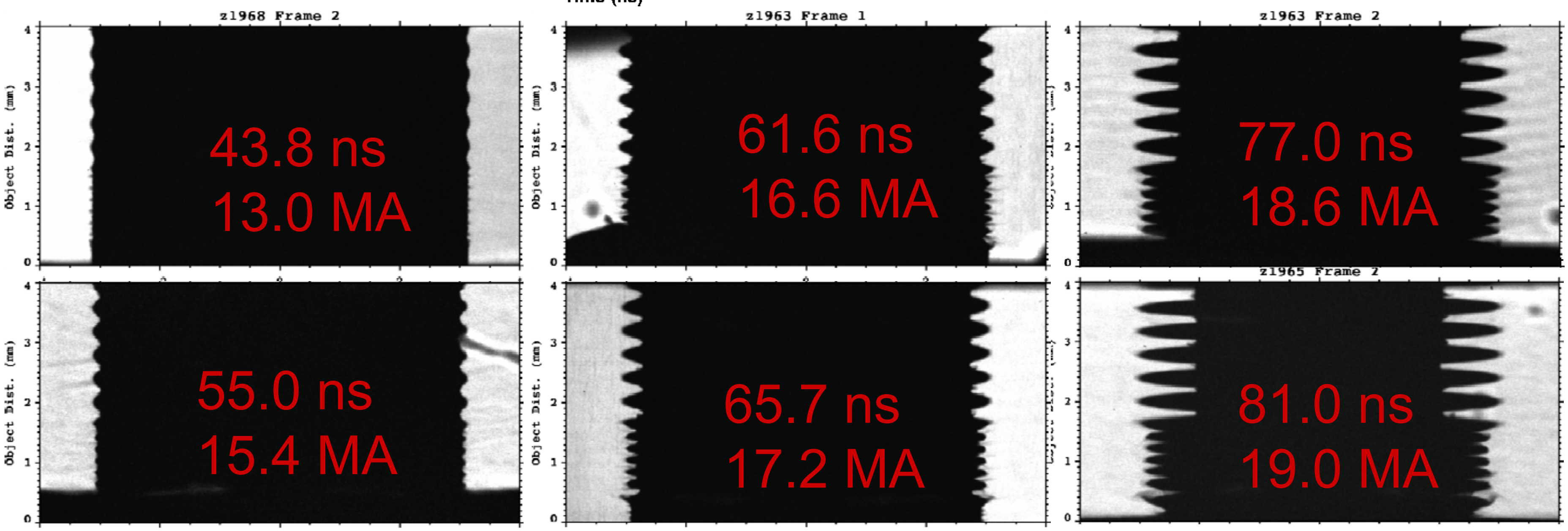
Experiments have validated LASNEX simulations of Magnetic Rayleigh Taylor (MRT) Instability.



- D. Sinars et al. PRL **105**, 185001 (2010) and Physics of Plasmas **18**, 056301 (2011)
- Lee, More, Desjarlais QMD corrected electrical conductivities, M. P. Desjarlais, Contrib. Plas. Phys. **41**, 2-3, 267 (2001).



Experiments and Gorgon 3D simulations agree about multi-mode MRT growth.